

*Idaho National Engineering and Environmental Laboratory*

# **“SMART PIPE” INTEGRAL COMMUNICATION, DAMAGE DETECTION, AND MULTIPLE SENSOR APPLICATION IN PIPELINES**

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# ***Need***

## Industry Identified Needs

- DOE sponsored industry workshops identified need for “Smart Pipe” that can provide:
  - Warning of damage on natural gas pipes
  - Use the pipeline as the  
" information/communication system"
  - Provide information on the health/performance of pipeline

# ***Requirements For A Damage Detection System***

- **Damage Detection**
  - Impact damage
    - o Determine when pipe damage occurs from impacts such as construction equipment
  - Damage due to distributed strain on the pipe
    - o Determine when pipe is subjected to damaging strain resulting from events such as earth movement or presence of heavy equipment
- **Damage Location**
  - Locate position of damage within a single 40 ft pipe section on a 27 km pipeline segment
- **Quantify Damage**
- **Data Communications**
  - Transmit damage detection data to receiving station without significant loss of signal

# Technical Approach

- Use **thermally sprayed conductive trace** on the pipe wall to sense, locate, and quantify the damage
- Use the pipeline/conductive trace as the communication pathway for transmission of damage information
- Link conductive trace with external monitoring and communication systems

# ***Thermal Spray Technology***

- Thermal spray is a group of processes that deposited fine metallic or nonmetallic powders (or wire)
  - On a metallic or nonmetallic substrate
  - In a molten condition
  - By passing the material through a heat source and gas flowstream
- Thermal spray is utilized to provide surface coatings of different characteristics
- The coating may be hard or soft, conductive or insulation
- Coating properties are controlled by changing machine process parameters and set up to achieve
  - Different compositions, densities, porosities, bonding strengths, electrical properties

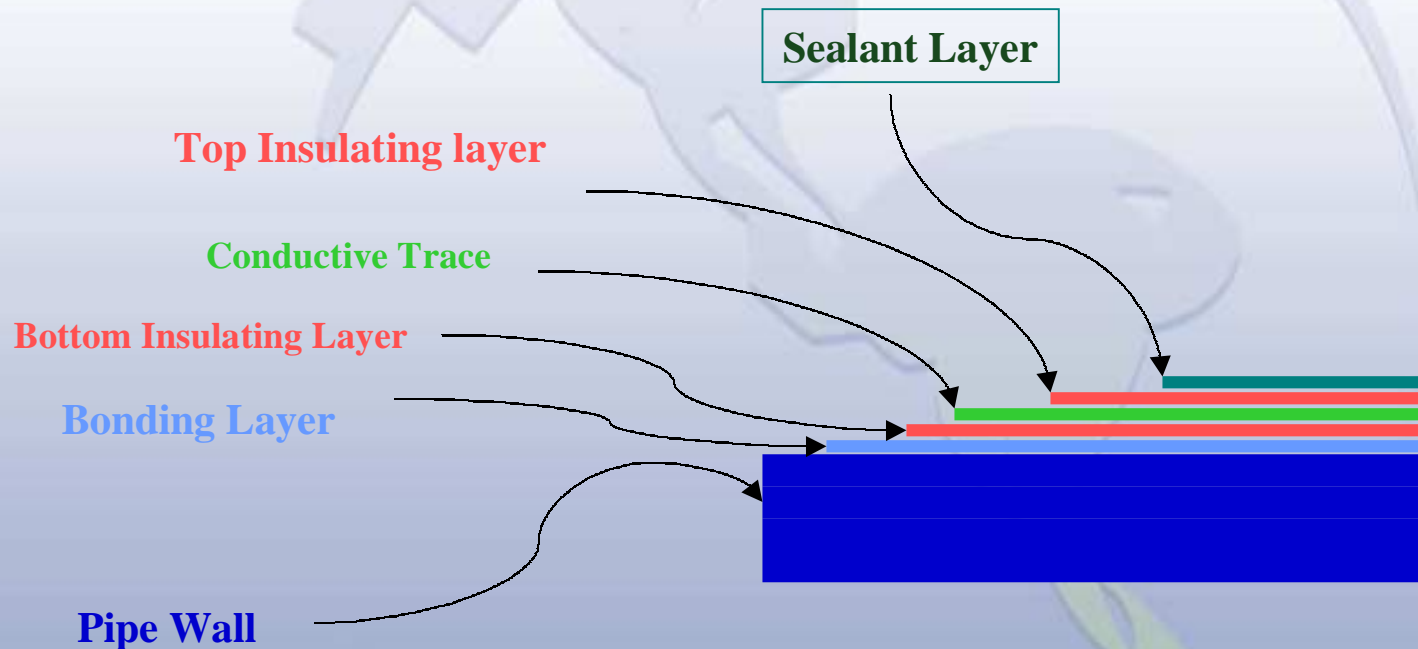
# ***State of the Technology***

- Thermal spray technology well established
- Can use metallic or nonmetallic materials
- Established technology to interface sprayed coatings with data transmission systems

# ***Conductive Trace Design***

- In this application multiple composite traces
  - 5 layers of a variety of materials
  - ~ 0.020 inches thick
- The layer closest to the substrate will be a bond coat
  - Covering any damage/debris on the wall
  - Create a controlled surface for the next layer
- The second layer is an insulating layer
  - Separating the conductivity of the substrate from the conductivity of the third layer
- The third layer is the conductive trace
  - Damage detection sensor
  - The pathway to transmit damage detection signals
- The fourth layer is the insulating top cover
  - The width of this data transmission line will be  $< 0.300''$
- The fifth layer is a protective sealant coat

# Proposed System As Applied to A Pipe Wall

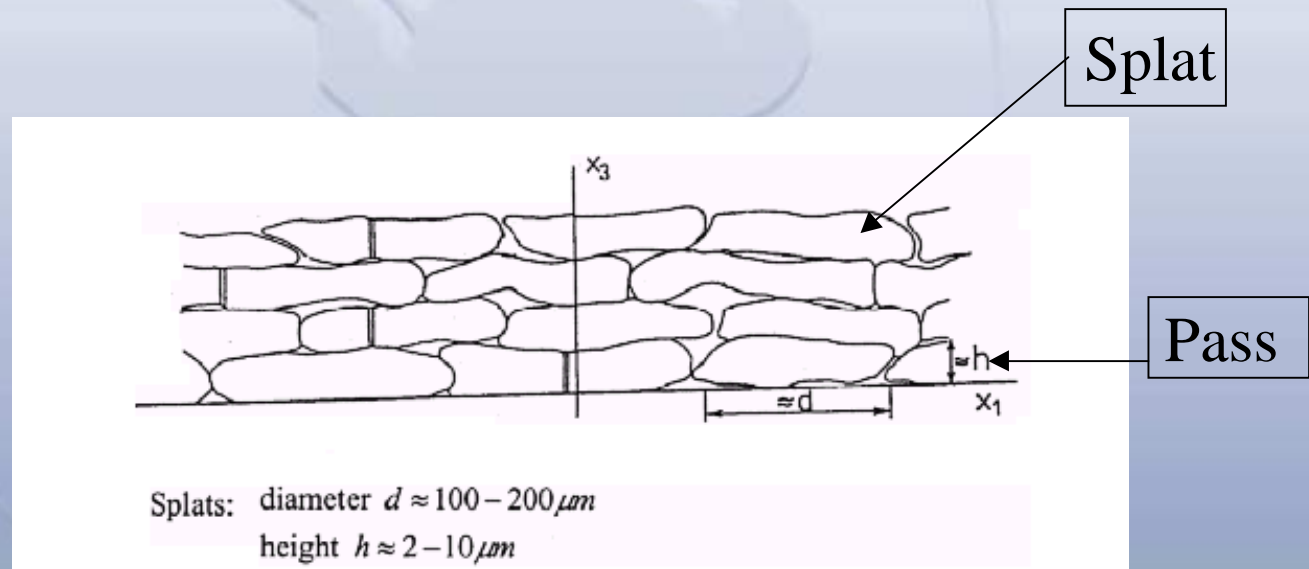




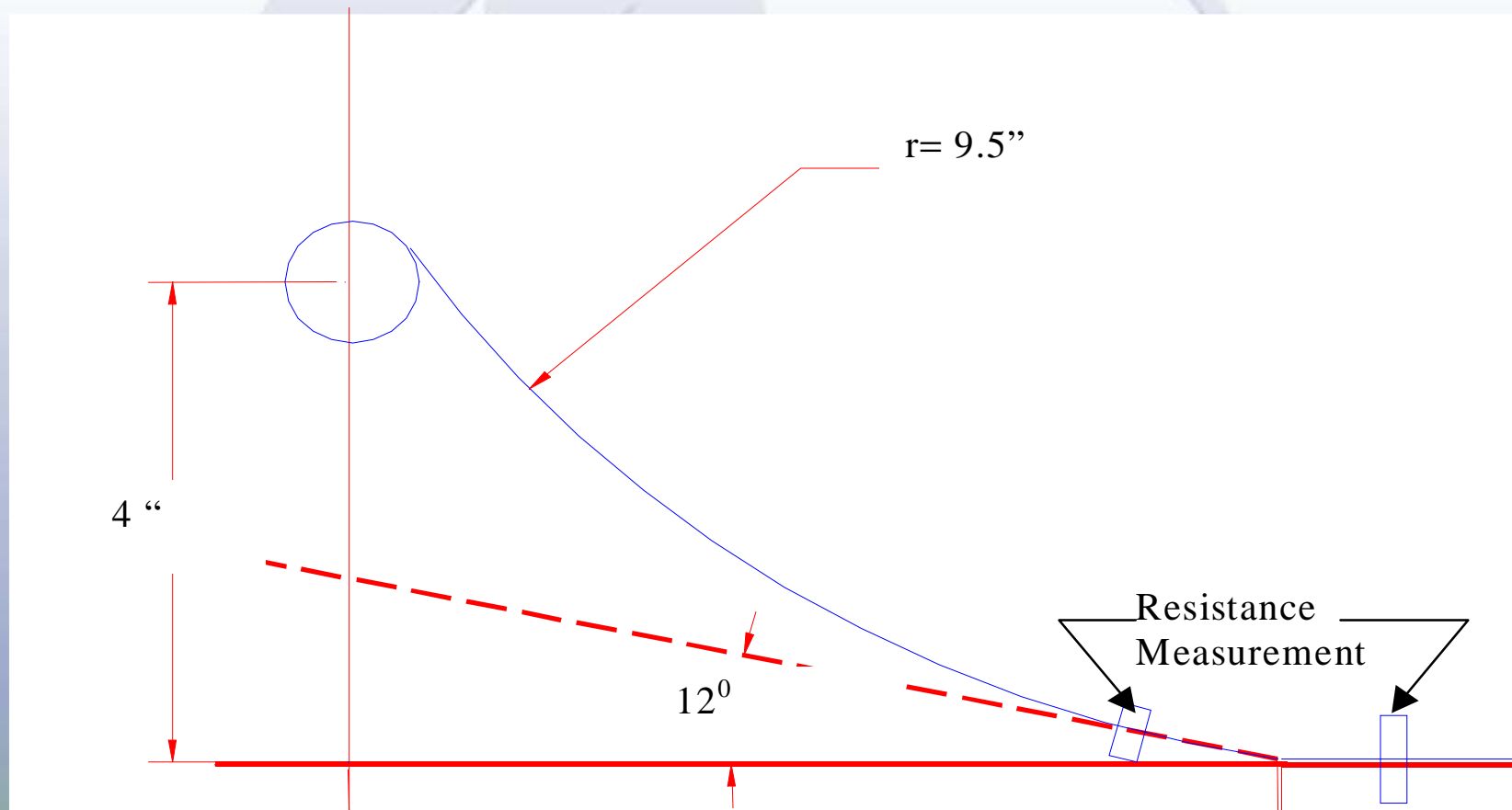
## ***Change in Resistivity***

- Resistance = resistivity \* (length/cross sectional area of the trace)
- Resistivity of solid conductors remains constant under strain
- Resistivity of thermal sprayed conductors increases under strain due to the voids in between the metal splats. The path of the current becomes more tortuous.

Each layer is created by passes that lay down splats.



## Initial test of the concept



Strain (micro inches/inch)	Coupon 7 (%)	Coupon 11 (%)	Coupon 20 (%)	Coupon 32 (%)	Coupon 54 (%)	Coupon 66 (%)	Coupon 72 (%)	Coupon 81 (%)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,000	0.00	1.00	0.50	1.50	2.00	0.50	0.50	5.00
2,000	0.00	3.00	2.00	4.00	5.00	2.00	2.00	10.00
3,000	0.50	7.50	5.00	6.00	9.00	4.50	5.00	15.00
4,000	6.50	14.00	10.00	11.00	10.00	10.00	10.00	22.00
5,000	13.50	26.50	18.00	15.00	11.50	13.00	18.00	28.00
6,000	17.50	26.50	23.00	18.00	12.50	17.50	23.00	23.00
7,000	23.00	29.00	29.00	24.00	15.00	29.00	29.00	29.00
8,000	27.00	32.00	-	29.00	20.00	32.00	38.00	32.00
9,000	32.00	36.00	-	34.00	-	36.00	46.50	36.00
9,700	37.00	38.00	-	39.00	-	38.00	-	37.00

## **Traces Applied to Outer Pipe Wall**



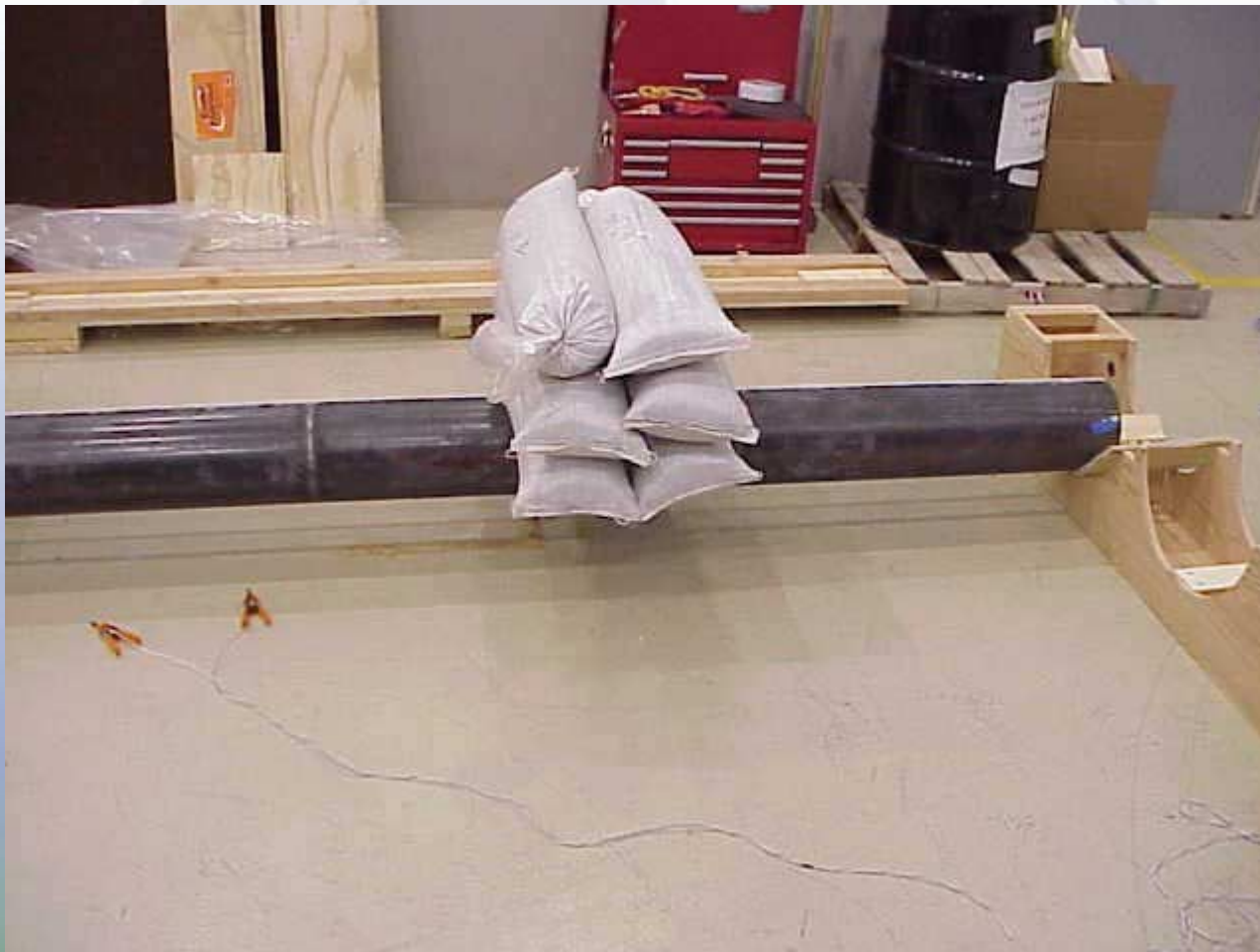
# Traces Applied to Inner Pipe Wall



# ***Detection of Distributed Strain***

- Tests planned mid September on 3" x 9' pipe
- Test will strain the pipe to the plastic deformation region

# ***Distributed Strain Test***



## ***Distributed Strain***

To produce 10,0000 microstrain on a 3 in diam pipe in the lab

$l$	96 inches
$\epsilon$	10,000.00 micro strain
$\sigma$	2.96E+05 lbs/in <sup>2</sup>
M	5.10E+05 lb-in
P	21,262.67 lbs



# ***Impact Damage***

Tests were conducted on 8" x 9' schedule 40 pipe

Pipe was "dented" using a backhoe

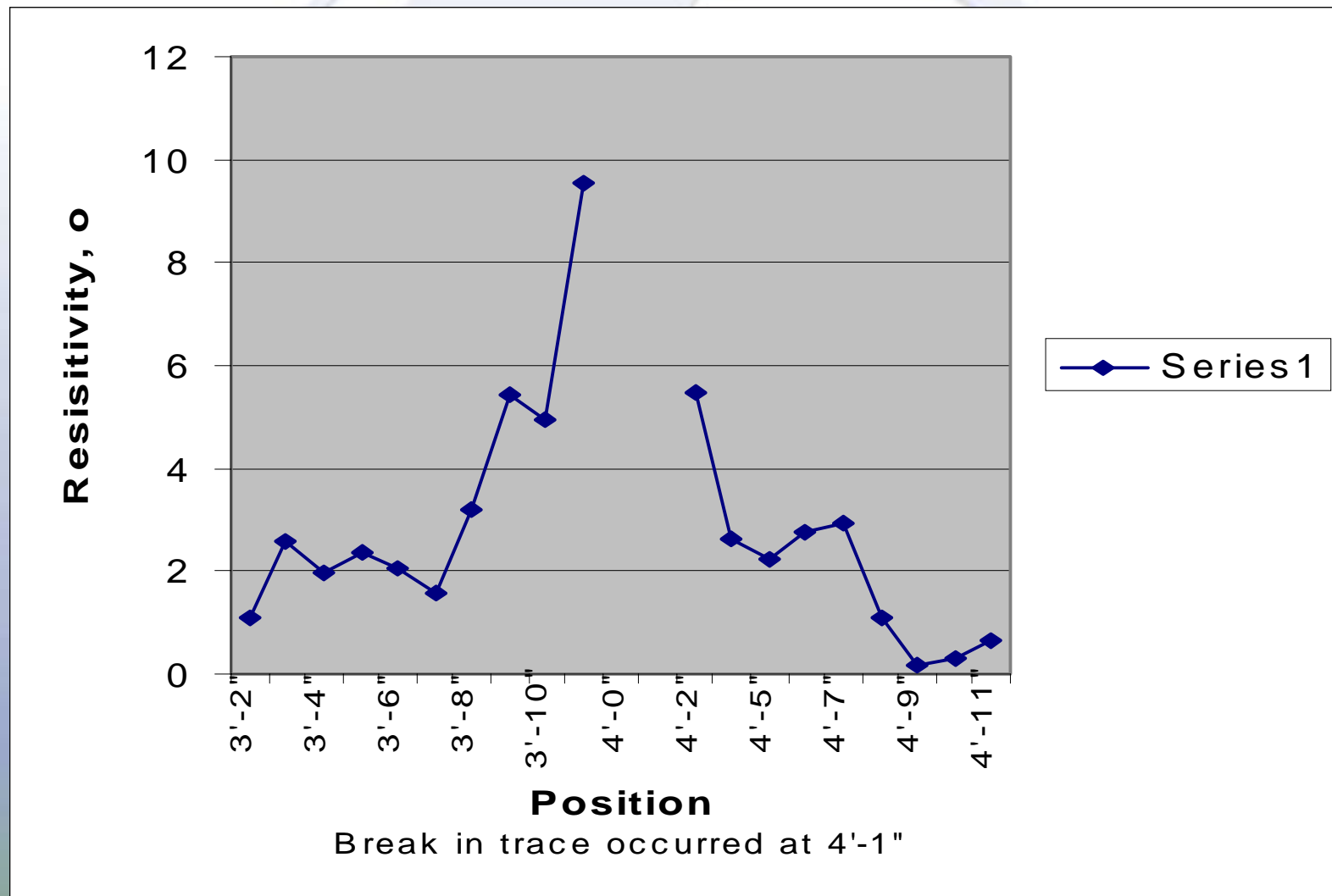
# Impact Damage Test



## ***Impact Damage Test***



## Impact Damage - Resistivity vs Position

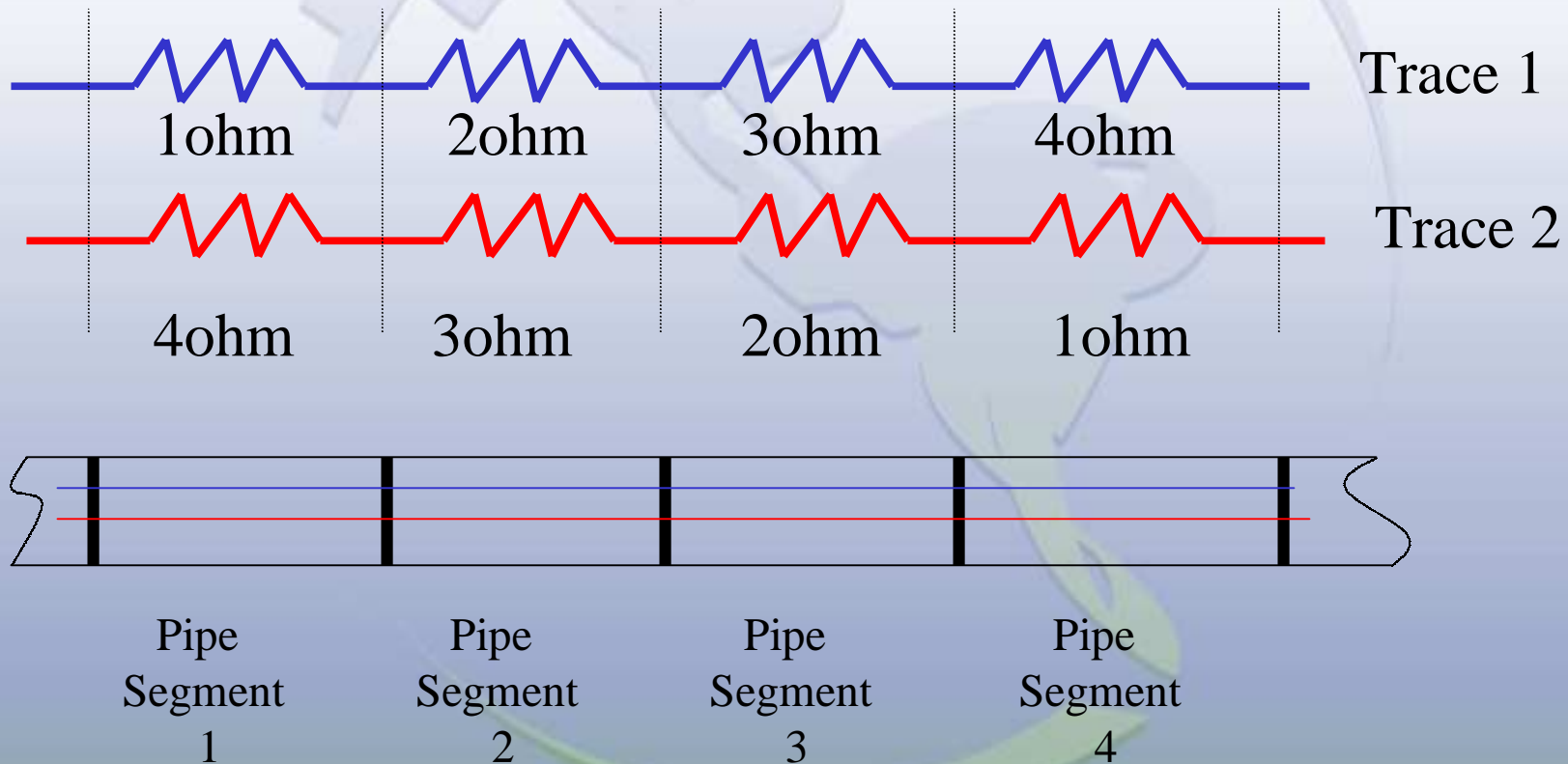


# ***Damage Location***

## **Approach**

- Create a conductive trace topology that contains parallel traces with unique combinations of resistive values on each pipe segment
- Using unique ratio of change of resistance under strain as a pointer to specific location

# Damage Location



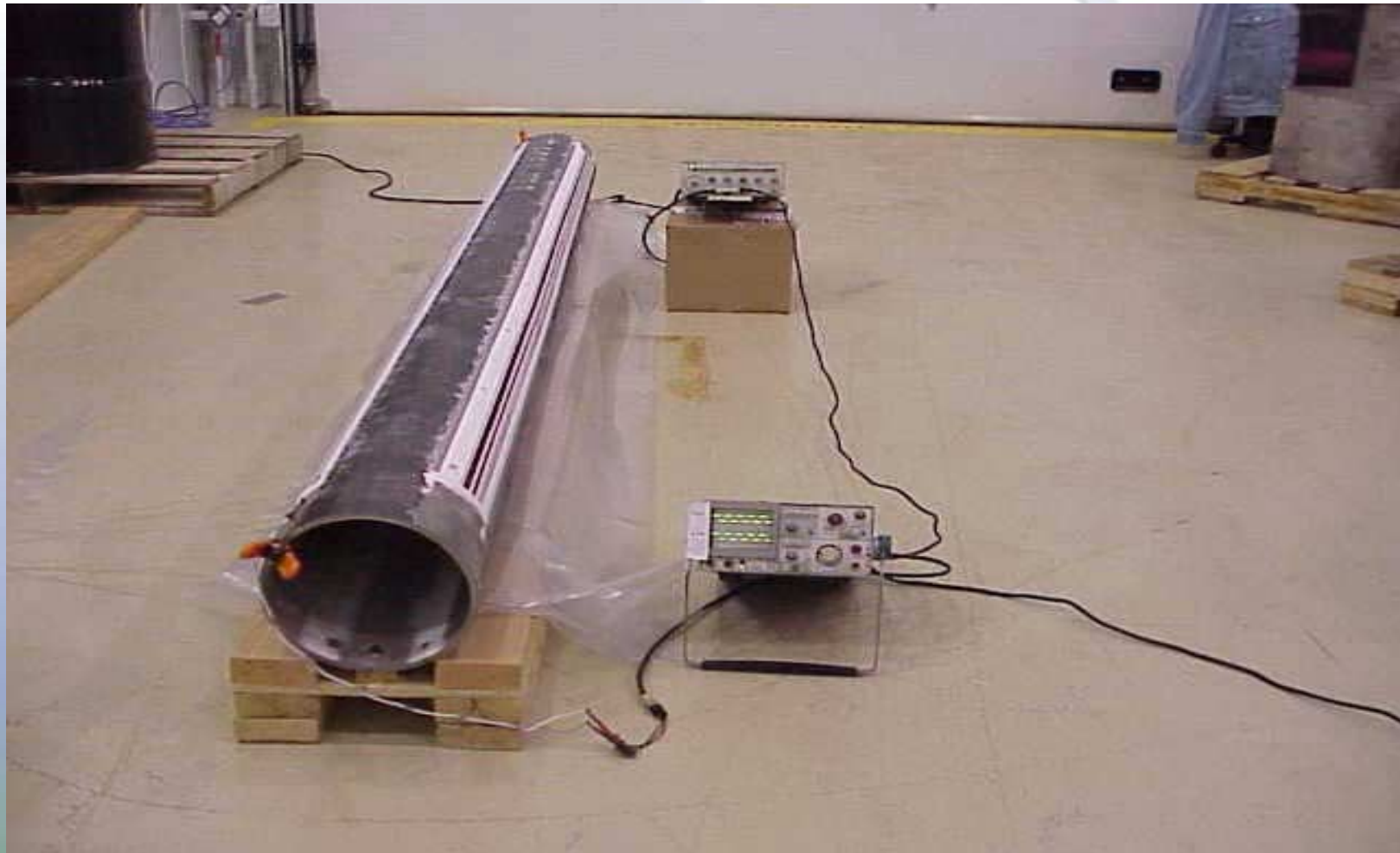
# ***Damage Communication***

## **Communication Tests**

- input signal - 2V peak-to-peak sine wave
- attenuation was measured over four decades spanning 100Hz to 13 MHz



# Thermal Spray Channel Communications Test

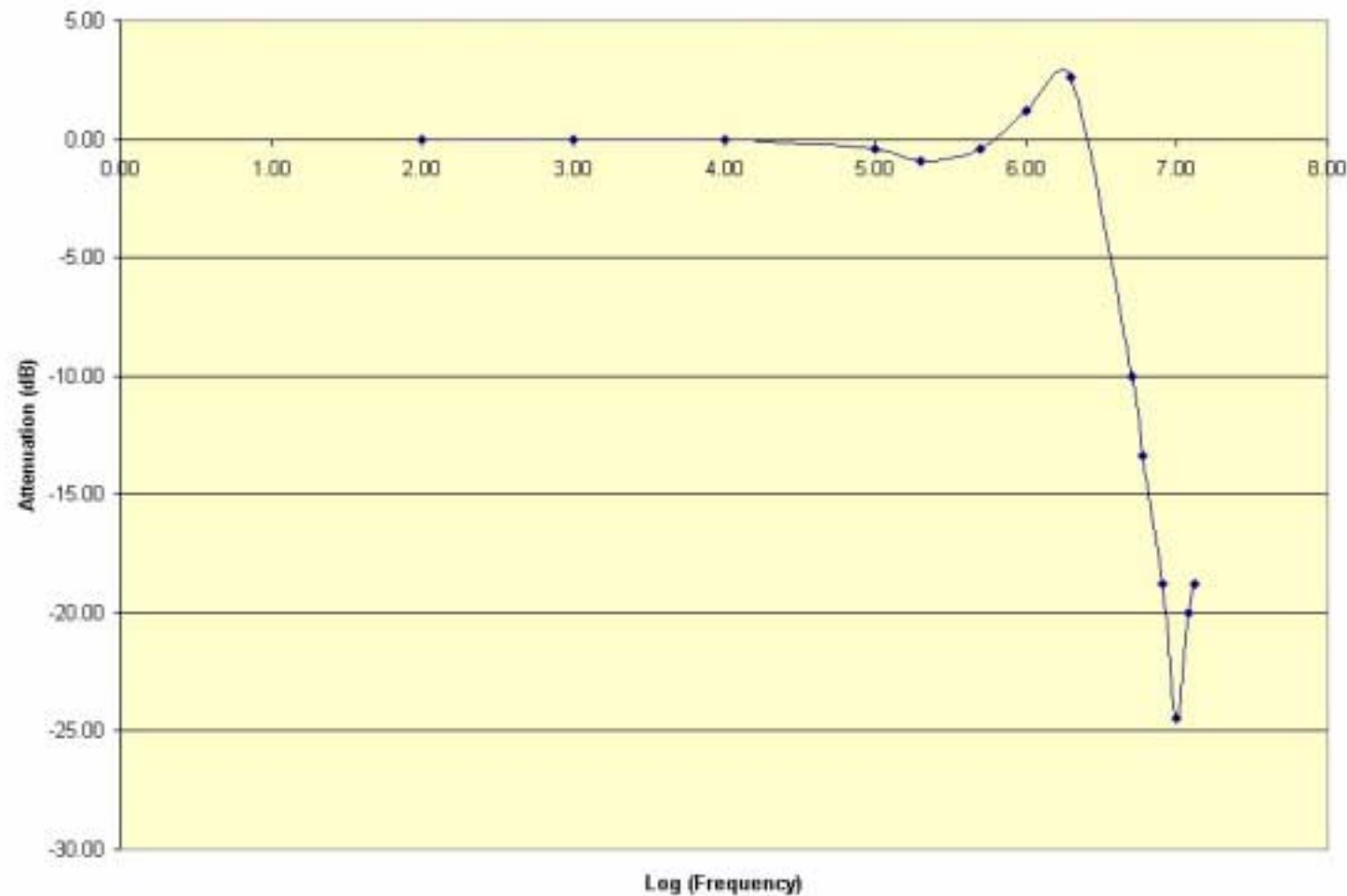




# ***Trace Communication Potential***

- With a maximum transmission loss of 40 dB  
(Which should yield a readily detectable signal)
- Traces can be used to communicate information at a bandwidth of 10kHz up to a distance of 27 km.
- Decreasing resistivity will increase the distance or data rate.
- Variations in mean resistivity of the trace material can change these results

# Transmission Characteristic of Thermal Trace



## ***Current Status***

- Strain - Resistivity relationship demonstrated on flat plate
  - Trace properties (porosity, oxide content) are being correlated to
    - machine parameters
    - performance measurements
- Ability to spray traces to required specifications has been demonstrated
- 3" by 9' and 8" by 9' pipes with multiple traces has been fabricated and tested at INEEL
  - Ability to detect impact damage has been demonstrated
  - Ability to detect distributed strain has been demonstrated

# Challenges

- Ability to spray trace over the distances and with tolerances required for production application
- Integrate the determination of location and magnitude of strain into a resistance measurement
- Demonstrate that we can communicate data over the thermally sprayed traces

## ***Future Work***

### **FY 03**

- 50 foot 18" diameter test section will be prepared for testing
  - Fabricated from 10 and 20 foot pipe sections
- Test piece will be shipped to GTI for field testing

### **FY 04**

- Develop and demonstrate system for pipe mill and field application

### **FY05**

- Demonstration at a gas pipeline site